Air-Sea Exchanges of Fresh Water: Global Oceanic Precipitation Analyses

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1. PROJECT SUMMARY

Oceanic Fresh water flux is an essential component of the global water cycle and plays an important role in forcing the oceanic circulation. However, its mean state, short-term variability and long-term changes are poorly monitored and documented due to undesirable qualities of the data sets for its two primary components, precipitation (P) and evaporation (E). Two major factors restricting the quality of existing oceanic fresh water flux data sets are 1) the lack of an extensive and continuous network of in-situ observations for calibrating and verifying each component, and 2) insufficient efforts to synthesize analyses for E and P. The availability of many new observation-based and model-produced data sets, especially precipitation, surface air temperature, sea surface temperature, humidity, and wind, makes it possible to quantitatively calibrate, verify and refine the existing P and E products.

In the past decade, two sets of satellite-based precipitation products have been developed at NOAA's Climate Prediction Center (CPC) that are used to monitor precipitation variations over global oceans. The CPC Merged Analysis of Precipitation (CMAP, Xie and Arkin 1997) is defined by merging individual products of satellite estimates derived from infrared (IR) and microwave (MW) observations. The CMAP data sets are created on a 2.5^{o}lat/lon grid over the globe and on monthly and pentad (5-day) time resolution for a 28-year period from January 1979 to the present. The other CPC oceanic precipitation analysis is that generated by the CPC Morphing Technique (CMORPH, Joyce et al. 2004) for high temporal / spatial applications. Cloud/precipitation movement vectors are first computed from high-resolution infrared image data in 30-min intervals observed by geostationary satellites. These movement vectors are then used to separately 'propagate' precipitation systems observed (by more-physically-based but less frequently sampled PMW observations) both forward/backward in time from "past"/"future" PMW scans to get the analyzed fields of precipitation at the targeted times. By weighting the forward and backward propagated rainfall estimates by the inverse of their respective temporal distance from scan time, these separate propagations are then morphed. The CMOPRH precipitation analysis is produced on an 8kmx8km grid over the globe from 60^{o}S to 60^{o}N and on 30-min intervals from December 2002. Both CMAP and CMORPH have been widely used by scientists around the world to a variety of applications including monitoring and assessment of global climate, model verifications and studies on global water budget/flux.

Further refinements of the CMAP and CMORPH are needed to improve their capacity to quantitatively document the precipitation variations and fresh water flux over the global oceans. The objectives of this project are to improve the CMAP and CMORPH precipitation analyses over ocean and to examine the fresh water flux as seen in the existing observations and in the NCEP Global Oceanic Data Assimilation System (GODAS). Specifically, we will

1) Provide the CMAP and CMORPH gridded analyses of oceanic precipitation, *together with estimates of uncertainty*, for a range of spatial and temporal scales consistent with data availability. Each product will be accompanied by a historical set of analyses of varying duration. The several products will be updated and made available to the various communities of interest as promptly as the availability of input data permit, with lags ranging from less than one day to 3 months.

2) Monitor and assess the global oceanic fresh water flux using our precipitation analyses several of the available oceanic evaporation products and compare them with that generated by the NCEP operational Global Oceanic Data Assimilation System (GDAS). As part of this activity, we will examine the uncertainty of the fresh water flux derived from the current generation of observed precipitation and evaporation analyses to get insight into to what extent the differences between the flux in GODAS and observation are attributable to problems of the model.

3) Perform a set of modular research and development tasks to address critical shortcomings of the current precipitation analyses and to improve the existing products.

2. FY 2007 ACCOMPLISHMENTS

2.1 CMAP Global Precipitation Analyses

This part of our research project involves two components: 1) documentation of the global oceanic fresh water flux using the CMAP and other observation-based data sets of precipitation and evaporation; and 2) Continuous updates and improvements of the current CMAP for better quantitative applications over ocean. In FY2007, we have focused our efforts on the examination of the quantitative uncertainties of the currently available oceanic precipitation and evaporation data sets and applied the observation data to assess the oceanic fresh water budget in several NCEP model-based products with consideration of uncertainties in the observations.

Three sets of widely used precipitation data sets are used here to define the ‘best possible’ observation of oceanic precipitation. These include the CPC merged analysis of precipitation (CMAP, Xie and Arkin), the Global Precipitation Climatology Project (GPCP) gauge-satellite merged analysis (Adler et al. 2003), and the Tropical Rainfall Measurement Mission (TRMM) merged precipitation analysis. Arithmetic mean of and root mean square (RMS) differences among the three data sets are computed for each grid box and defined as the ‘best guess’ of oceanic precipitation and the proxy index of its quantitative uncertainties, respectively. Largest uncertainties of oceanic precipitation analysis are observed over tropics along the rainbands associated with the ITCZ and over high latitude oceans where satellite observations are less reliable (fig.1). On average, uncertainties of the analyses are about 10% of the precipitation amount.

Similar calculations are performed for oceanic evaporations using four popular observation-based data sets, including the satellite-based products of the GSSTF2 of Chou et al. (2003), the HOAPS3 of Grassl et al. (2000), and the J-OFURO2 of Tomita et al. (2007), and the COADS-based SOC climatology of Josey et al. (1998,1999). Uncertainties of the observed seasonal climatology of oceanic evaporation are around 10% of the magnitude of mean climatology, with larger uncertainties over eastern Pacific and oceanic regions around the Maritime Continent (fig.2). Combined, the observed long-term mean of precipitation (P) and evaporation (E) presents net fresh water coming into/out of the ocean in tropics/subtropics, respectively, with a quantitative uncertainty of 10-15% in the annual/seasonal mean climatology defined by the currently available observation data sets (fig.3).

Seasonal and interannual variations of global fresh water flux generated by the NCEP operational Global Data Assimilation System (GDAS), Reanalysis 1, Reanalysis2, Global Forecast System (GFS) atmospheric model and the Climate Forecast System (CFS) coupled ocean-atmosphere model are then examined against the observations described above. NCEP reanalysis 2 is utilized to force the Global Oceanic Data Assimilation System (GODAS) and initialize the CFS climate forecast model, while the GDAS is an analysis system taking advantage of the state-of-the-art modeling technology and newly available observation inputs. Among the five NCEP model-based products examined here, Reanalysis 1 reproduced the magnitude of E and P very well, while all other products tend to produce excessive amount of both E and P over the ocean (fig.4).

Interannual variations (monthly anomaly) of precipitation are reasonably well captured by the NCEP GDAS and the two reanalyses, especially over tropical Pacific and the northern Atlantic (not shown), while those of evaporation presents good agreements with the observations over most of the extra-tropical oceanic areas (fig.5). The state-of-the-art NCEP Global Data Assimilation System generates both the oceanic precipitation and evaporation fields with better agreements with the observations than the NCEP reanalyses, indicating potential of further improvements upon the current generation reanalyses through refined models and enhanced input observation data (figure not shown). Substantial differences in the evaporation over tropical oceans are attributable to multiple factors including differences in the state variables (surface wind, air temperature and humidity) and the bulk algorithms used to compute the evaporation used in both the models and the observation data sets. Further work is underway to determine the contribution of each factor.

To support our efforts of monitoring and examinations of oceanic precipitation, the monthly and pentad CMAP precipitation have been updated throughout FY2007. As of November 2007, the standard version of the monthly and CMAP precipitation data sets have been updated through September 2007, while the real-time version pentad CMAP data set has been updated on a quasi-real-time basis, available one day after the end of each pentad period.

2.2 CMORPH Global Precipitation Analyses

The overall goal of this part of our project is to improve the CMORPH and to apply the technique to produce high-resolution oceanic precipitation for an extended period. Although the CMORPH analysis are available for recent years when we have microwave observations from multiple satellites, the high space and time resolution of the analysis makes it a powerful means to monitoring and assess the oceanic precipitation of meso- to synoptic scales over the global oceans from 60^{o}S to 60^{o}N.

Our original plan for FY2007 focused more on the back extension of the CMORPH high-resolution precipitation analysis beyond December 2002. Due to the delay in upstream input satellite data and the migration of CPC computer systems, we had to adjust our work plan and carried out other tasks that are critical to the accomplishment of our goal. The following is a list of the tasks we have accomplished during FY2007:

- Improvement of a retrieval algorithm to derive precipitation from AMSU satellite observations

Our CMORPH technique defines precipitation analysis by combining information from estimates made from individual satellites. Refinement of the precipitation estimates from these individual satellites is fundamental to the success of our project. During FY2007, we actively participated in the development of a new algorithm to derive precipitation from satellite microwave observations of AMSU led by our colleagues in NOAA/NESDIS. The new algorithm takes advantage of cloud liquid water derived from the AMSU-A instruments and a convective index computed from the 183GHz channel data, yielding precipitation estimates with much improved quality than those based on AMSU-B instrument observation alone and used as one of the inputs to our CMORPH technique. The new AMSU estimates derived from this new technique will be used to replace the current AMSU data in near future. A paper describing the algorithm has been published in *J. Geophys. Research.*

- Regional validation and global examinations of the new AMSU algorithm

A comprehensive evaluation is performed for the precipitation estimates derived from the new AMSU algorithm described above. Such examination is critical to better understand the quantitative behavior of the estimates before they may be incorporated into our CMORPH merging technique. For this purpose, precipitation estimates derived from both the new and old AMSU algorithms are examined using data from NOAA 15, 16, 17, and 18 for July 2005. These AMSU-based precipitation estimates are then compared against the high-quality surface rainfall estimates generated by the TRMM “2A12” algorithm (Kummerow, 1998). Both the AMSU-based estimates and the TRMM “2A12” products are remapped to a 0.25^{o} lat/lon grid, and collocated observations from the AMSU and TRMM that occurred within 30 minutes of each other were retained to calculate the statistics.

Our comparison showed that the new AMSU estimates present much better comparison statistics than the old AMSU estimates (Weng et al. 2003). In general, the correlation of the new AMSU estimates with the TRMM data is higher than that of the old estimates, especially over southern hemisphere (fig.6). While the old AMSU algorithm over-/under-estimates precipitation over tropics/high latitudes, respectively, the new algorithm generates precipitation estimates with a latitudinal profile much close to that of the high-quality TRMM product (fig.7). Raining area of the new AMSU estimates, however, is smaller than that of the TRMM estimates, suggesting that the new AMSU algorithm still tends to overestimate heavy rainfall events compared to the TRMM (fig.8).

Differences between the new and old AMSU estimates are examined over various parts of the global oceans. Over the tropical oceanic regions, the new algorithm produces an overall reduction in the rainfall amount (fig.9), while overall rainfall frequency shows an increase, especially in subtropical anticyclonic regions (fig.10). For mid-latitudes, an increase in the amount and frequency of rain events is observed over the ocean with the estimates derived from the new algorithm, especially poleward of 25^{o} in both hemispheres (fig.9&10). It is also notable that the new estimates are in a good agreement over oceanic regions when compared with other PMW techniques (i.e., SSM/I GPROF V6) and high quality collocated retrievals (TMI 2A12) at global and regional scales.

Based on these results, we concluded that the precipitation estimates produced by the new AMSU algorithm present better performance in representing the spatial distribution, temporal variations and frequency of rainfall events with various intensity and will be used to replace the current AMSU estimates.

- Extend the CMORPH period of record back beyond December 2002

Currently, CMORPH high resolution precipitation estimates are available for a period from December 2002 to the present. As an important part of this project, we are in process of extending the CMORPH data record back for the period before December 2002.

In order to perform this task, it is necessary to retrieve precipitation estimates derived from passive microwave sensors (SSMI, AMSU-B, TMI, AMSR) in the form of “orbit by orbit” files. Precipitation estimates derived from these passive microwave observations are generated by scientists in NASA/GSFC, NOAA/NESDIS and other institutions and used as inputs to our merging processes. To date, we have acquired approximately 90% of the necessary passive microwave data from all available sources back to 1998. Currently we are waiting for the retrospective reprocessing of the GPROF V6 algorithm for the SSMI instruments aboard the DMSP satellites.

In order to extend the CMORPH record to before December 2002, it is also necessary to retrieve global, ½ hourly, native resolution (~ 4 km) IR data from the 5 geosynchronous meteorological satellites that, when combined, afford complete global coverage in longitude. Fortunately, these data were saved by CPC back to late 1998. However, the data were saved in raw ("McIDAS") format on several hundred CDROMs. Thus, a non-trivial effort was expended in FY2007 to copy the data on the CDROMs to tapes. This effort will enable the global merging and QC of the IR data prior to its use in the CMORPH processing.

- Reprocess the entire CMORPH period of record using a frozen system in which all recent improvements have been incorporated

As described before, we had to defer this task to next fiscal year due to the delay in the SSM/I-based precipitation estimates and the technical difficulties caused by the migration of computer systems at CPC.

3. PUBLICATIONS

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Xie, P., W. Wang, J.E. Janowiak, M. Chen, C.L. Shie, and L. Chiu, 2007: Seasonal and interannual variations of fresh water flux over the global oceans in the NCEP CDAS, CDS2, GDAS, GFS and CFS. *IUGG 2007 General Assembly*, Perugia, Italy, July 2-13, 2007.

Xie, P., W. Wang, J.E. Janowiak, M. Chen, C.L. Shie, and L. Chiu, 2007: Examining fresh water flux over global oceans in the NCEP CDAS, CDAS2, GDAS, GFS and CFS. *NOAA 32nd Climate Diagnostics and Prediction Workshop*, Tallahassee, FL, Oct.22-26,2007.

Xie, P., W. Wang, J.E. Janowiak, M. Chen, C.L. Shie, and L. Chiu, 2008: Examining fresh water flux over global oceans in the NCEP CDAS, CDAS2, GDAS, GFS and CFS. *Third WCRP International Conference on Reanalysis*. Tokyo, Japan, Jan. 28 – Feb.1, 2008.

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Tomita, H., M. Kubota, S. Iwasaki, T., Hihara, and A. Kawatsura, 2007: Introduction of J-OFURO version 2 surface heat flux data set and its analysis over the North Pacific. *AGU 2007 Joint Assembly*, Acapula, Mexico, May 22-25, 2007.

Weng, F., L. Zhao, G. Poe, R. Ferraro, X. Li and N. Grody, 2003: A1MSU cloud and precipitation algorithms, *Radio Science, vol. 38(4)*, pp. 8068-8079.

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FIGURES

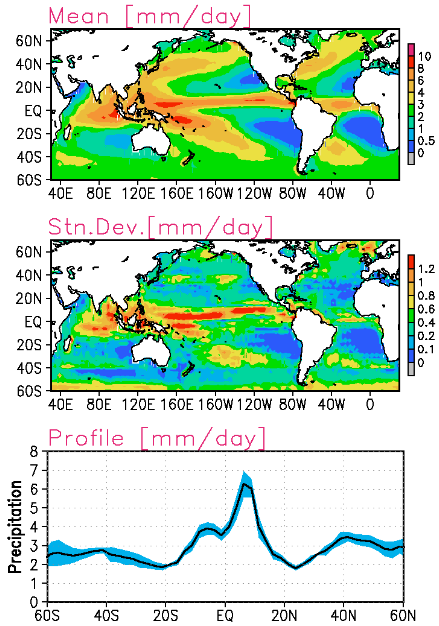

Fig. 1

Global distribution of the arithmetic mean (upper) and standard deviation (middle), together with their zonal means (bottom), among the annual mean precipitation (mm/day) from three sets of widely used observation-based data sets: the CMAP (Xie and Arkin 1997), GPCP (Adler et al. 2003) and the TRMM TMI-PR merged analysis. Arithmetic mean and standard deviation of the zonal means are plotted as solid line and blue shading, respectively, in the bottom panel.

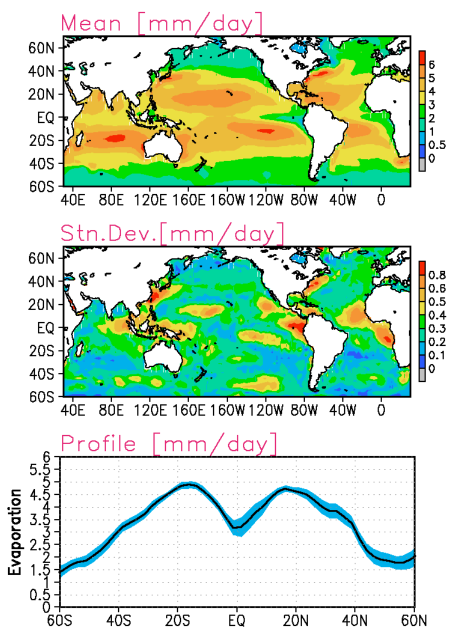

Fig. 2

Same as in figure 1, except for evaporation from four sets of observations data sets: the GSSTF-2 of Chou et al. (2003), the HOAPS3 of Grassl et al. (2000), and the J-OFURO2 of Tomita et al. (2007), and the COADS-based SOC climatology of Josey et al. 1998,1999.

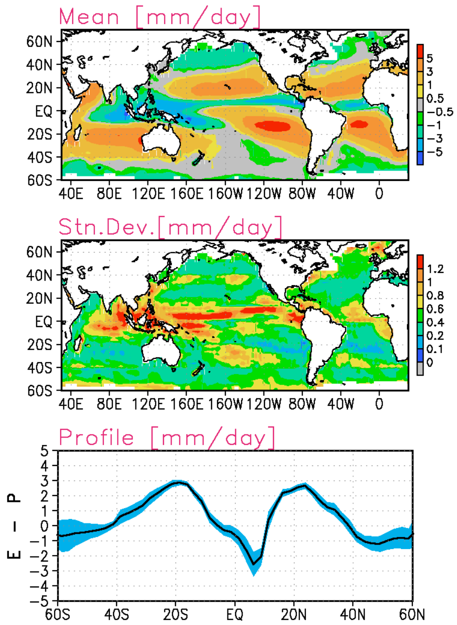

Fig. 3

Same as in figure 1, except for the fresh water flux (evaporation-precipitation, mm/day).

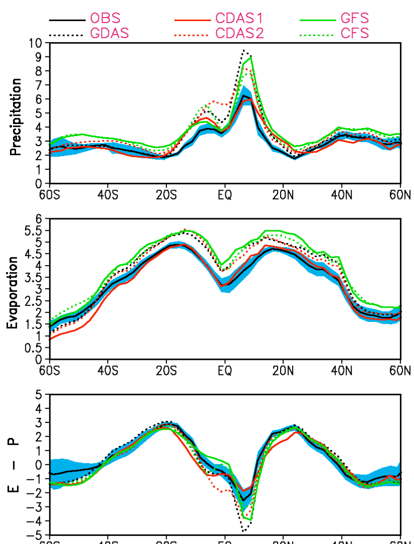

Fig. 4

Latitudinal profile of annual mean zonal mean precipitation (mm/day, upper), evaporation (mm/day, middle), and fresh water flux (mm/day, bottom), as derived from the observations and several NCEP model-based products. The black line indicates arithmetic mean while the blue spread shows the standard deviation among the individual data sets used.

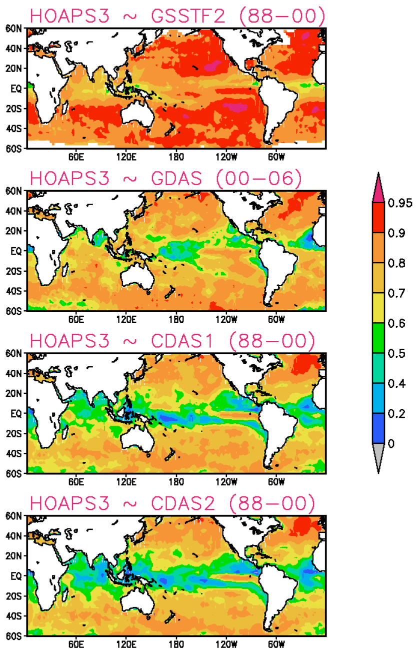

Fig. 5

Anomaly correlation between the monthly evaporations derived from a) the HOAPS3 and GSSTF2 satellite-based estimates (top); b) HOAPS3 and GDAS (2nd from top); c) HOAPS3 and NCEP Reanalysis 1 (3rd from top); and d) HOAPS3 and NCEP Reanalysis 2 (bottom).

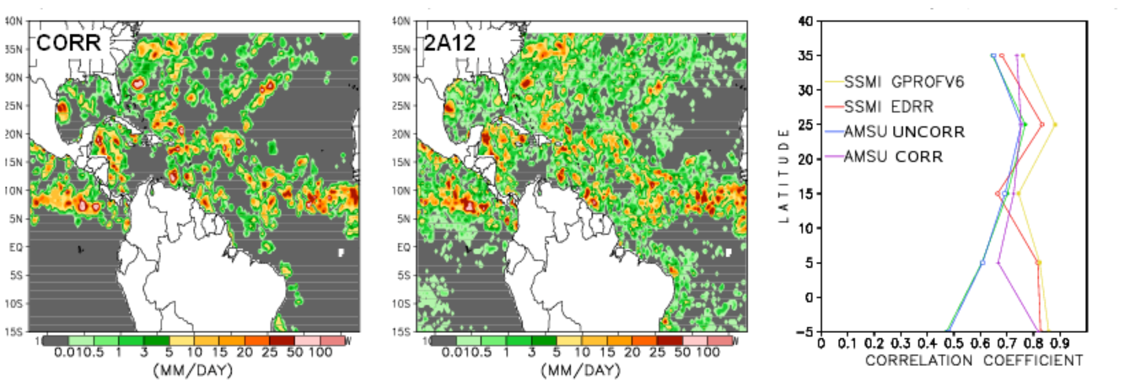

Fig.6: Left panel: Mean rain rate for the new AMSU estimates over Atlantic Ocean from 1-31 July 2005. Central panel: Idem for TMI 2A12. Only scenes within 30 minutes are considered in the average. Right Panel: correlation coefficient of different estimates compared against TMI 2A12. Results for the new and old AMSU are marked as "AMSU CORR", and "AMSU UNCORR", respectively.

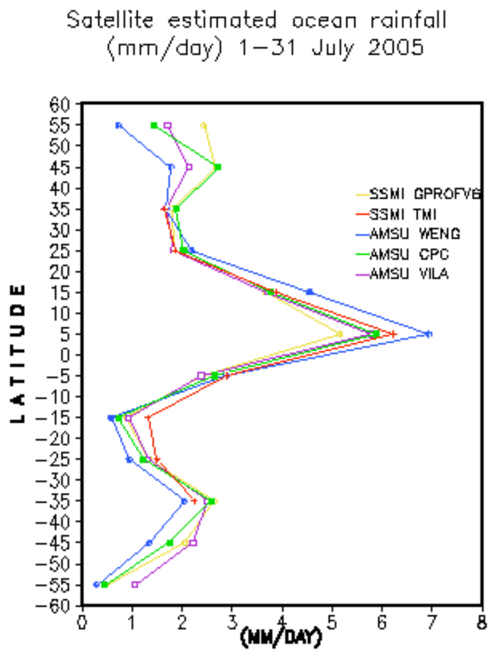

Fig. 7:

Oceanic passive microwave estimated rainfall from various sensor/algorithms for July 2005 averaged in 10 degree latitude bands. The new and old AMSU estimates are marked as "AMSU VILA" and "AMSU WENG", respectively.

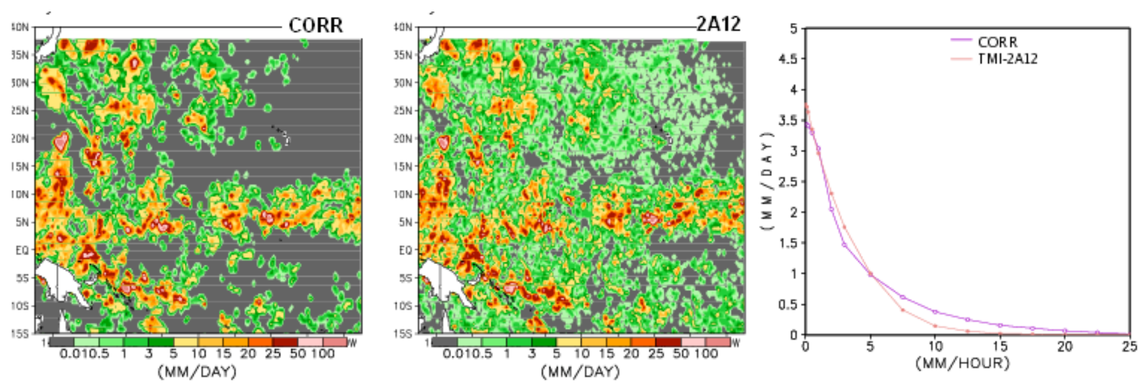

Fig. 8: Left panel: Mean rain rate for new AMSU estimates over western Pacific Ocean from 1-31 July 2005. Central panel: Idem for TMI 2A12. Only scenes within 30 minutes are considered in the average. Right Panel: Rain rate distribution for AMSU CORR and TMI 2A12.

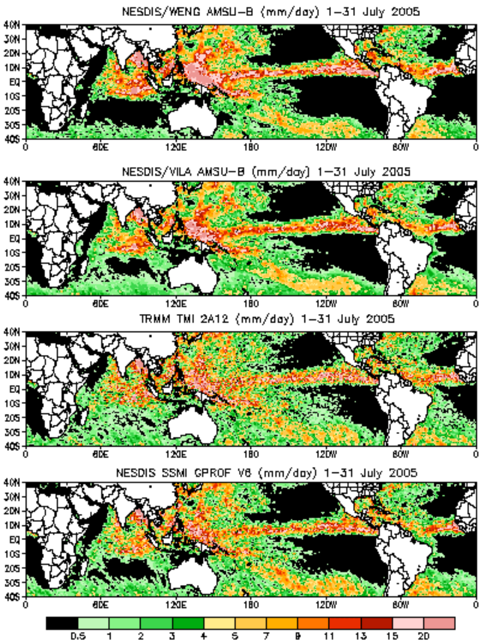

Fig. 9:

Spatial distribution of passive microwave estimated rainfall for July 2005 derived from a) the old AMSU algorithm (top), b) the new AMSU algorithm (2nd from top), c) TRMM TMI 2A12 (3rd from top), and d) the NESDIS SSMI GPROF V6 (bottom).

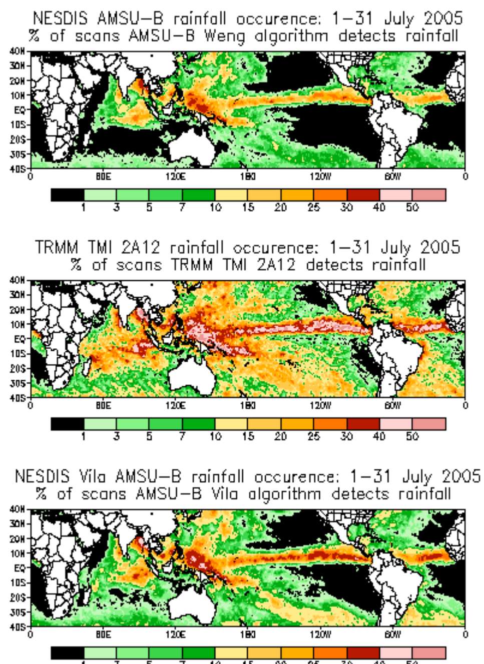

Fig. 10:

Spatial distribution of frequency of rain events for July 2005 detected from a) the old AMSU algorithm (top), b) the TRMM TMI 2A12 (middle), and c) the new AMSU algorithm (bottom).